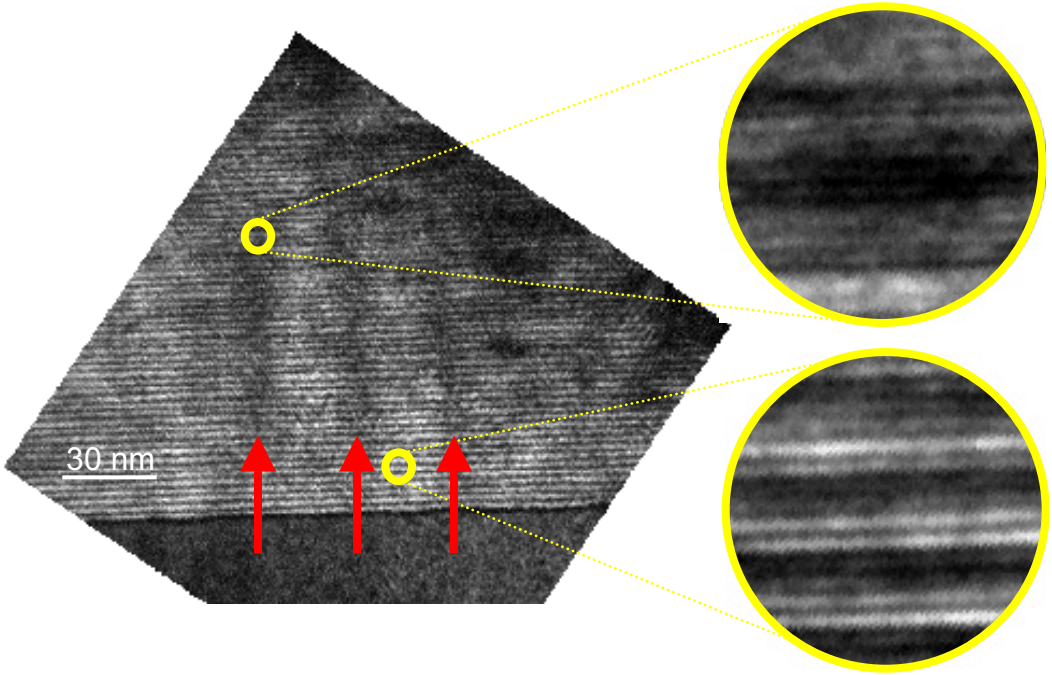
Lateral Composition Modulation in (GaAs)(GaSb) Multilayer Structures



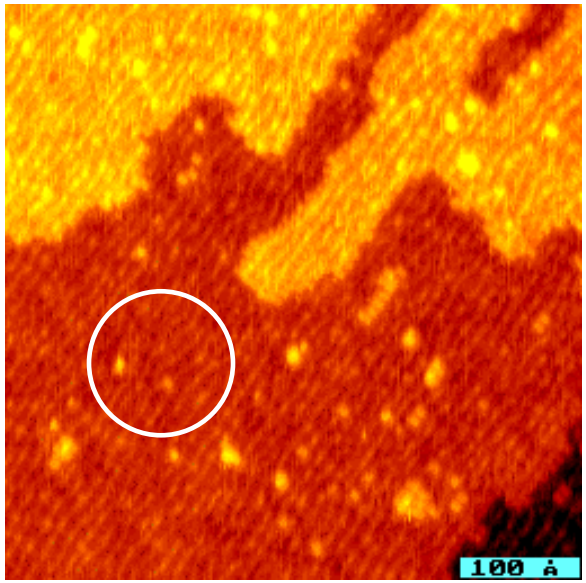
Mirecki Millunchick
DMR-9973352

An alternative method to obtain an array of nanometer-sized structures is by spontaneous phase separation in alloy films. For example, regular and robust phase separation in the direction perpendicular to the growth direction has been observed in short period superlattices (SPS). From these structures several different types of optoelectronic devices have been fabricated with novel and improved properties. For example, lasers with lower threshold currents and better temperature stability have been fabricated utilizing this material. In all cases to date, the phase separation has been observed on the metal sublattice.

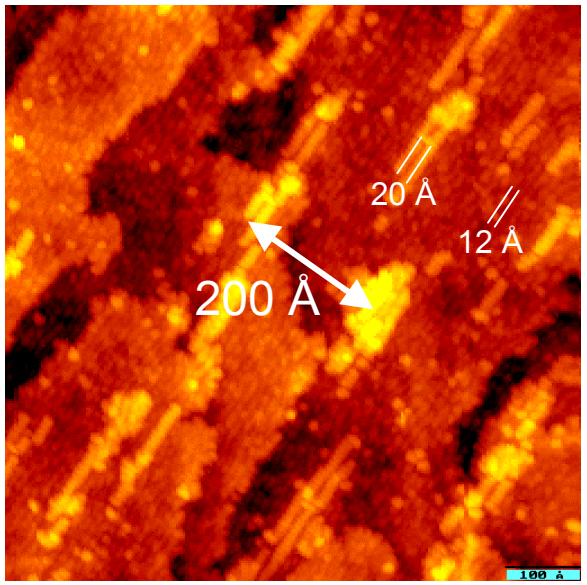
Mixed anion compound semiconductor alloys such as InGaAsSb are useful for thermophotovoltaic applications. In those devices, it has been observed that phase separated material posses higher quantum efficiencies. However, obtaining reproducible arrays of these materials has been problematic. We have demonstrated for the first time the spontaneous formation of lateral composition modulation on the Group V sublattice. This figure shows a Cross sectional Transmission Electron Micrograph of a (GaAs)(GaSb) short period superlattice (where each layer is 2 monolayers thick). Each layer of the superlattice structure is clearly visible in the image, and arrows point to the phase separated regions. The modulation wavelength varies between $150<\Lambda<230$Å and the Sb compositions vary between $0.73\leq x^{Sb}\leq 0.77$ in the Sb-rich regions and $0.33\leq x^{As}\leq 0.55$ in the As-rich regions. The phase separation does not form immediately; rather, it develops only after several periods of the superlattice are deposited (see the lower inset). As more of the structure is deposited, the layers thicken in certain areas (see upper inset), forming the modulated regions. By controlling the growth of these layers, we will be able to tailor the amount of phase separation on both sublattices and obtain novel high efficiency devices.

This nugget is an example of how detailed atomistic experimentation and a thorough understanding of materials growth can lead to structure/property fine tuning. Understanding the formation mechanisms for these structures will enable a vast array of low dimensional optoelectronic devices.

The Origin of Phase Separation



InGaAs/InP random alloy



(InAs)(GaAs) multilayer structure exhibiting nascent composition modulation

Mirecki Millunchick
DMR-9973352

Even though spontanteous lateral composition modulation has been observed in a number of materials systems, the mechanism for its formation is not known. This portion of the research is to examine the surface morphology of the the growth front on an atomic scale in order to understand the mechanisms for phase separation specifically, and interface formation in general.

This figure shows Scanning Tunneling Micrographs of two nominally lattice matched InGaAs films deposited on InP(001) substrates. The micrograph on the left is that of a random alloy. Note the surface morphology consist primarily of large terraces. Also visible on the image are meandering and discontinuous As dimer rows (circled). Typical STM images of binary compound surfaces show dimer rows that are straight and continuous. The fact that the dimer rows are winding on alloy surfaces may have a large impact on the surface and step energies, thus the evolution of the surface morphology.

The micrograph on the right shows an STM image of an (InAs)(GaAs) short period superlattice (where each layer is 2 monolayers thick), which is just beginning to phase separate. Superimposed upon the reconstructed surface similar to that observed in the random InGaAs alloy, is a distribution of dimer chains that are approximately 150Å long and spaced 200Å apart. This spacing is on the same order as lateral composition modulation observed in these structures. Therefore, we hypothesize that these dimer chains are enriched in indium and nucleate the phase separation. This conjecture is supported by the fact that the dimer chains have a wider spacing (20Å) than the underlying dimer rows (12Å).

This nugget is another example of how detailed atomistic experimentation and a thorough understanding of materials growth can lead to structure/property fine tuning. Examination of the surface morphology on the atomic scale will aid in the development of new theories for thin film growth.

Diversity in the Mirecki Millunchick Research Group

- From top left: Assistant Professor Joanna Mirecki Millunchick, Benny Perez-Rodriguez, Catalina Dorin, and Chris Lane
- From bottom left: Yunqing Chen, Assistant Professor Chris Pearson, Grant Martin, Alexandru Riposan, and Mathieu Bouville.

Mirecki Millunchick
DMR-9973352